RESEARCH HIGHLIGHTS

Technical Series 02-109

COMPOSITE MASONRY WALL TIES

Overview

Steel masonry wall ties may corrode, which can lead to cracking, bulging or even partial collapse of a building's exterior wall.

A masonry tie is a small piece of steel connecting together two layers of wall referred to as wythes. The outer layer or wythe is masonry, and the inner wythe is either a concrete block wall or a steel or wood stud wall. The tie is used in one of two ways. It can make the two wythes act together in resisting applied loads, either both gravity and lateral loads or, more commonly, lateral load only. Alternatively, it can be used to transfer lateral loads to the inner wall. This allows the outer wythe to be thin and act primarily as a first line of defence against environmental elements.

Although buried in walls, masonry ties are still exposed to moisture and air which infiltrate the mortar. This leads to their corrosion. Eventually, the ties lose their load-carrying capacity and break. Problems become noticeable only when a number of ties fail, resulting in visible cracking, bulging or partial collapse of the exterior wall. Even with these visible signs, it is difficult to determine the extent of the problem without removing a large portion of the wall or conducting a tedious local investigation using a borescope.

Composite materials, a relatively recent innovation, potentially offer an alternative to stainless steel. With that in mind, this research project was undertaken to develop a prototype masonry tie using composite materials.

Fibre reinforced polymer composites (FRPC) have been used extensively in the aerospace, transit, car and chemical industries, as well as in sports equipment manufacturing. In contrast, their structural application, specifically in road and bridge infrastructures in cold climates, is a newer phenomenon. Research into new materials has been encouraged by the considerable expense involved in repairing corroded steel reinforcements, caused by de-icing chemicals, in concrete and steel bridges with concrete decks. FRPC is gaining popularity in refurbishing bridge decks, and in repairing and strengthening concrete members and structures subjected to sea water. First used in a pedestrian bridge in 1990, FRPC has since been used in highway bridges subject to heavy vehicular loads, but is still limited to modest spans.

In order to design a suitable prototype, it is necessary to understand a wall tie's function, the properties of the material used and current construction practices. To accomplish this, the research project involved the following steps:

- researching cavity wall construction literature and the problems associated with this type of wall system
- studying performance problems associated with corrosion of steel anchors and ties in masonry
- reviewing design standards for masonry ties and developing design criteria
- studying the properties of FRPC and their structural application
- applying the design criteria to FRPC and designing composite tie prototypes
- testing the prototypes to determine their properties
- providing conclusions and recommendations.

Several prototypes were developed and tested. The most promising result was an adjustable tie manufactured from glass fibre reinforced polymer composite (GFRPC), which could be used between an exterior masonry veneer and a concrete block back-up wall system with a 50-mm air space and 50-mm rigid insulation.

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Wall construction and ties

Cavity walls, the older of two exterior wall systems currently in use, typically use masonry for both wythes. The cavity is partly filled with insulation for better thermal performance, and waterproofing on the exterior surface of the interior wythe directs water to the outside. Changes in construction techniques led to the emergence of an alternative—the veneer wall system.

This newer system consists of a non-structural exterior wythe, supporting its own weight and wind load, and a structural backing, supporting lateral loads and possibly loadbearing as well. The exterior wythe serves as a rainscreen, and the space between the veneer and backing contains an air space, insulation, an air barrier and a vapour retarder. The cavity wall, however, is stronger and stiffer than the veneer wall due to the shear transfer between wythes.

Many problems with these wall systems started to appear in the 1980s, leading to extensive work on their design and the components, including masonry ties. Wall ties can corrode either in the cavity or embedded in the mortar. Steel corrosion occurs due to the oxidation of iron ions. The resulting hydrated iron oxide is what is known as rust.

A single tie is subjected to different conditions. It is embedded in mortar, passes through air space and insulation in the cavity, and is embedded or attached to the inner wall. This makes it more susceptible to corrosion than a metal fully enclosed in mortar. The life span of a tie is difficult to predict given the complexity of its condition and the considerable variations in its exposure to moisture and air.

In looking at performance specifications for ties, there are nine areas to consider:

1. *strength*—these include i) transfer of forces from the exterior to the backup wall, ii) allowance for differential movements horizontally and vertically (creep, shrinkage, and thermal and moisture expansion and contraction), and iii) the ability to perform during fire
2. *stiffness*—no excessive deformation in tension or compression
3. *durability*—must be compatible with the design life of the building
4. *water migration into interior*—the shape should allow water to drip into the cavity before it reaches the interior wythe, but this requirement in practice, specifically crimping ties to produce a drip, has been found to cause significant reduction in compressive resistance
5. *minimum protrusion into cavity space*—the wider the projection into the cavity the greater the potential for the tie to act as a conductor and collector of mortar droppings
6. *construction tolerances*—wall ties must tolerate the construction process: they must not be easily damaged or cause injury to workers, and they should allow for ease of installation of the membrane and insulation
7. *retains insulation and membrane*—support for both decreases the possibility of separation from the substrate, which can increase the possibility for accumulation of water
8. *economy*—production should be economical and consistent in outcome
9. *workmanship*—a good practice guide can assist with proper installation, to ensure performance expectations are met

Prototype design and testing

Composites use high-strength fibres in many different forms, combined with a variety of resins. The resins used to form a composite include epoxies, phenolics, bismaleinide and cyanate esters. There are different manufacturing processes, but common to all, and very important, is the application of controlled heat and pressure after laying. The most commonly used fibres are glass (e-glass or s-glass), aramid (also known as Kevlar) and carbon. Figure 1 gives the tensile strength properties of each, with structural steel included for reference.

Figure 1: Comparison of fibre properties

Fibre	Specific Gravity	Tensile Strength (MPa)	Tensile Modulus (GPa)	Tensile Strain at Breaking Load (%)	Relative Cost
E-glass by Owens Corning	2.6	3100 - 3800	75 - 78	4.5 - 4.9	Low - very economical
S-glass by Owens Corning	2.4	4600 - 4800	88 - 96	5.4 - 5.8	Medium
Aramid (Kevlar) by Dupont	1.4	3600	41 - 186	2.9 -8.7	Medium - high
Carbon by Hexcel	1.78	4200 - 6100	230 - 300	1.8 - 2.0	Medium - high
Structural steel 350W	7.8	450 - 650 (350 yield)	200	0.2 at yield 18 at ultimate 25 at failure	High

The FRPC material most readily available is produced by a pultrusion process. The resulting product has a dependable quality and is reasonably cheap. Problems arise from the limitation in shapes produced and a predetermined strong direction along the length of the material. There is a difference in strength between the lengthwise direction and the perpendicular direction of approximately 2 to 3. Comparisons for the direct tensile properties of different composites, based on pultruded shapes, are given in figure 2.

- Tensile failure of part B occurred either in a corner of the "U" or in the bottom centre of the "U".
- Strength failure of part A is consistently a bearing- or shear-type failure.
- Most strength failures causing delamination were brittle and occurred suddenly without warning.
- The compressive strength of the mortar did not appear to affect the bond between the tie and masonry.

Figure 2: Properties of composites

Composites	Fibre by Volume	Tensile Strength (MPa)	Tensile Modulus (GPa)	Tensile Strength at Breaking Load (%)
Glass fibre RPC	40% e-glass	138 - 206 (lengthwise) 69 (crosswise) 685 (rod)	12 - 17.2 (lengthwise) 6.5 (crosswise) 41.5 (rod)	1.15
Aramid RPC	58% aramid	1900 (rod)	118 (rod)	
Carbon RPC	50% carbon 55% carbon	600 (both directions) 1100 (rod)	70 (both directions) 120 (rod)	0.85 1.1 (rod)
Structural steel 350W	7.80	450 - 650 (350 yield)	200.00	0.2 at yield 18 at ultimate 25 at failure

The most common poltruded FRPC material on the market uses e-glass as reinforcement (GFRPC). Aramid (Kevlar) is significantly more expensive and considered a special order. The same applies to carbon FRPC, but with a still higher cost.

A two-part prototype design was developed, with part A being basically rectangular in shape and Part B being a U-shaped piece that fits through a slot in part A (see figures 3 and 4). Part A sits in the head joint (block) and Part B is the brick tie.

Testing of the prototype was done using a veneer wall system consisting of brick veneer, a 50-mm cavity, 50-mm rigid insulation, an air/vapour barrier and 190-mm concrete block backup. The prototype was tested for strength, pull out from masonry, pull out from the concrete block and compression.

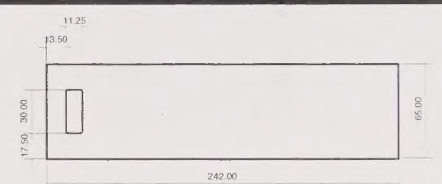
Results

The tests produced the following results:

- The tensile strength of the material proved to be the limiting factor in the design of the prototype. The weakest component was part A of the tie, which governs the tie's ultimate strength.
- Contrary to expectation, the bond was not a problem. Bond strength was well in excess of the tie's strength. Roughing the surface and mechanical anchorage did increase bond capacity, but this proved unnecessary.
- The snug fit of the two parts of the tie resulted in negligible free play.

Figure 3: Basic block tie design and variations

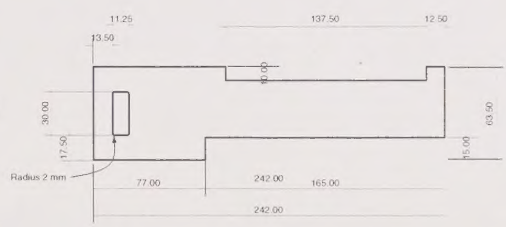
Part A-1



3.15 mm (1/8") Plate material

Figure 3a)

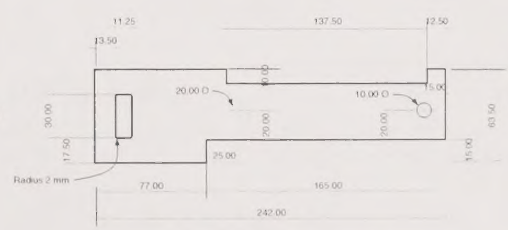
Part A-2



3.15 mm (1/8") Plate material

Figure 3b)

Part A-3

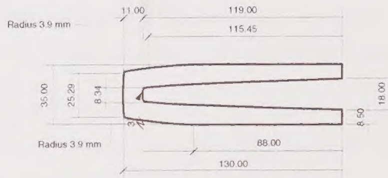


3.15 mm (1/8") Plate material

Figure 3c)

Figure 4: Basic brick tie design and variation

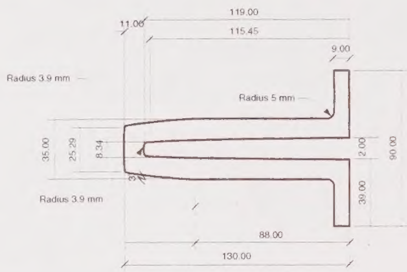
Part B-1



3.15 mm (1/8") Plate material

Figure 4a) - Basic brick tie

Part B-2



3.15 mm (1/8") Plate material

Figure 4b) - Brick tie with end returns

- The push through/compressive tests indicated that this type of failure is unlikely to occur.
- The material tested came from two different manufacturers, with the properties for the materials proving to be similar.

Implications for the housing industry

The outcome of this research suggests that an adjustable tie can be manufactured using GFRPC, for use in a veneer wall system with a 50-mm air space and 50-mm rigid insulation. Production of the prototype was labour-intensive, though, as it required precision cutting of the material to the desired shape. This process needs to be simplified, to reduce cost.

Additional research needs

Further research is needed to determine the tie's fire performance. The material is known to perform well, but it does become warm, and the effect of this on the tie needs to be understood. It is also important to determine the loads that have to be carried by the tie when exposed to fire. It may be possible to improve the properties of the material by selecting different resin, veil and finishing materials.

The pultrusion process should be investigated to determine if it can be altered to obtain more beneficial properties. For example, could a new moulding process be developed that uses laid fibres, as opposed to the short ones used in injection moulding? Research should also be undertaken to determine if a one-piece tie could be made from new thermoplastic (bendable) material produced by pultrusion.

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Housing Research at CMHC

Under Part IX of the *National Housing Act*, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research.

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